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ABSTRACT

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Investigations were conducted to determine whether the effects of tillage practices on the prevalence of brown stem rot of soybean (caused by *Phialophora gregata*), *Heterodera glycines*, and *Phytophthora sojae* were confounded by soil texture in samples collected in the fall of 1995 and 1996. Soil and soybean stem samples, along with tillage information, were collected from 1,462 randomly selected fields in Illinois, Iowa, Minnesota, Missouri, and Ohio in collaboration with the National Agricultural Statistics Service. The incidence of brown stem rot was determined from 20 soybean stem pieces collected from each field in a zigzag pattern. The detection frequency of *P. sojae* (expressed as percent leaf disks colonized) and population densities of *H. glycines* were determined from soil cores also collected in a zigzag pattern. The soil samples were grouped into various textural classes, and the effect of soil texture and tillage relations on the activities of each pathogen were determined. Both tillage and soil texture affected the incidence of brown stem rot; however, there was no interaction between tillage and soil texture. Conservation tillage had a greater ($P < 0.05$) incidence of brown stem rot in clay loam and silty clay loam than did conventional tillage. The detection frequency of *P. sojae* was not affected by tillage, but a tillage × texture interaction ($P = 0.013$) indicated that the effect of tillage depended on soil texture. There was a greater ($P < 0.05$) detection frequency of *P. sojae* in conservation tillage than in conventional tillage in silt loam and loam soils. However, in sandy loam, the detection frequency of *P. sojae* was greater ($P = 0.0099$) in conventional tillage than in conservation tillage. Population densities of *H. glycines* were significantly affected by both tillage and soil texture, but overall, there was no tillage × texture interaction. There was an inverse relationship between population densities of *H. glycines* and percent clay ($r = -0.81$, $P = 0.01$) in no-till fields, but little or no change in nematode densities was observed with increasing clay content in tilled fields. Population densities of *H. glycines* were less ($P < 0.05$) in no-till fields than in tilled fields in silty clay loam and clay soils. There was no difference in *H. glycines* densities between the tillage categories in soils sandier than silty clay loam or clay. The findings emphasize the need for cautious interpretation of the effects of tillage practices on diseases and pathogens in the absence of information on soil texture.

Additional keywords: leaf-disk bioassay, minimum tillage, soybean cyst nematode.

Soil texture and tillage directly or indirectly influence various biological and chemical properties of the soil. Soils varying in texture differ in water-holding capacity because of variations in pore-size distribution (25,28). Similarly, tillage practices, especially conventional tillage versus conservation tillage, vary in their impact on the water status of the soil because of the differences in residue management and soil compaction (5,17). Consequently, the effect of tillage practices on a particular soilborne pathogen may be modified by the soil texture.

The effects of soil texture and various tillage practices on some plant diseases and pathogens have long been understood. The abundance and activities of many plant pathogens, especially those of zoosporic fungi such as *Phytophthora* spp., were associated more with fine-textured than coarse-textured soils (10,30,31), whereas conservation tillage practices, especially no-till, generally are associated with greater disease severities than are conventional tillage practices (2,20,26,27). Despite the overwhelming evidence that both soil texture and tillage practices affect plant diseases, the impact of the interaction between the two factors has never been investigated for any disease or pathogen. Virtually all previous studies compared two or more tillage practices on soils with a single textural class (13,26,34) or vice versa (24,29,39). Information on how tillage-texture relationships affect soilborne plant pathogens in general is lacking.

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Brown stem rot of soybean (caused by *Phialophora gregata*), *Phytophthora sojae*, and *Heterodera glycines* are three of the most important diseases or pathogens of soybean in the north-central United States (8). Recent investigations of their prevalence in randomly selected fields showed that they were widely distributed in the region and their incidence was affected by tillage practices (36,37). The incidence of brown stem rot and the detection frequency of *P. sojae* were greater in conservation-till than in conventional-till fields. Conversely, fields that had various forms of tillage operations had greater incidence and population densities of *H. glycines* than did no-till fields. Even though significant differences between the tillage systems were observed using large samples from randomly selected fields covering wide geographic areas, the possible confounding effects of soil texture were not known.

Edaphic factors that affect the water status of the soil affect the activities of *Phytophthora* spp. in general (11,30). The effect of tillage practices on activities of *P. sojae*, therefore, may vary in soils with varying texture. There is ample evidence that soil texture also affects population densities of *H. glycines*. Soil texture has been shown to affect *H. glycines* establishment (33), population densities (9), reproduction (39), spatial distribution (24), and associated soybean yield losses (15). Even though soil disturbance is reported to increase *H. glycines* population densities (38), information on the effects of tillage practices is inconsistent. Tyler et al. (34), Koenning et al. (16), and Workneh et al. (36) found that population densities of *H. glycines* were greater in tilled fields than in no-till fields. However, Hershman and Bachi (13), Niblack et al. (23), and Stienstra et al. (32) observed either no difference or inconsistent differences between tillage treatments. As suggested by

Koenning et al. (16), the conflicting reports may be due to differences in soil texture.

Currently, conservation tillage practices (no-till and mulch-till) in the north-central United States are on the rise because of the increasing awareness of the importance of residue cover (4). A question often arises as to which tillage practices are appropriate for a particular soil texture in relation to plant diseases. Information on the effect of the interaction of soil texture and tillage practices is useful in determining the possible risks associated with choosing a particular tillage-texture combination.

In the fall of 1995 and 1996, the effects of tillage practices on brown stem rot, *P. sojae*, and *H. glycines* and their prevalence was assessed in soil and stem samples collected from Illinois, Iowa, Minnesota, Missouri, and Ohio (36). The primary objective of the work described in this article was to determine the effect of texture-tillage relationships on the incidence of brown stem rot of soybean, recovery of *P. sojae*, and population densities of *H. glycines* in the five states of the north-central United States.

MATERIALS AND METHODS

The current study is a continuation of previously reported research that described the effects of tillage practices on the prevalence and abundance of the three pathogens in samples collected from five states of the north-central United States (36). Data derived from the samples were used to assess the interrelationships of soil texture, tillage, and the activities of the pathogens. To avoid unnecessary repetition, only a brief description of the materials and methods is presented here. Details of methods of field selection, sample collection, and assessment of disease incidence or pathogen abundance were described previously (36).

Sample collection. In the fall of 1995 and 1996, soil and soybean stem samples, along with tillage information, were collected from 1,462 randomly selected fields using an area-frame sampling method (7,35) in Illinois, Iowa, Minnesota, Missouri, and Ohio in cooperation with the National Agricultural Statistics Service (NASS). In each field, NASS establishes and maintains two yield-assessment plots. From each field, 20 soybean stems (each 20 cm long, measured from the soil line) and approximately 1 liter of soil were collected from between the plots in a zigzag pattern. The samples were shipped to Ames by second-day express mail and stored at 4°C until they were processed. The texture of the soil samples was determined by a commercial laboratory (MVTL Laboratories, Inc., Bismark, ND).

Brown stem rot assessment. Each of the soybean stems was split longitudinally and visually examined for the presence or absence of the characteristic vascular and pith discoloration caused by *Phialophora gregata* (3). The presence of *Phialophora gregata* in arbitrarily selected stem samples with characteristic symptoms was verified by culturing pieces of the internal stem tissues on a selective medium for *Phialophora gregata* (PGM) (19) and acidified potato dextrose agar.

***P. sojae* bioassay.** *P. sojae* was isolated from the soil samples by the leaf-disk bioassay method (21) at 22.4 to 26.6°C in the greenhouse. Leaf disks (20 per sample) of the soybean cv. Sloan (susceptible to all known races) were floated on flooded soil in 475-ml plastic cups for 24 h and plated onto a selective medium (18). The percentage of leaf disks colonized by *P. sojae* was recorded after 4 days of incubation at 22 to 24°C in the dark.

***H. glycines* assays.** Two techniques were used to assess soil samples for the presence of *H. glycines*. A semiautomatic elutriator (6) was used to extract cysts of *H. glycines* from 100-cm^3 aliquots of soil from each sample. Each aliquot of soil was incubated for 30 min in a 15.75-g/liter solution of Electrasol automatic dishwasher detergent (Benckiser Consumer Products Inc., Dunbury, CT) to disperse the soil particles. This slurry subsequently was suspended in flowing water agitated by air in the elutriator. The soil suspension passed through a 250-μm-pore size sieve on which *H. glycines* cysts, if present, were trapped. Eggs of *H. glycines* were extracted from cysts by grinding the sediments collected on the 250-μm-pore size sieve with a stainless steel pestle with 1-mm-deep grooves at 2,500 rpm for 60 s (22). Finally, eggs were concentrated on a 25-μm-pore size sieve and were stained with acid fuchsin (22). Samples were observed and counted with a dissecting microscope at ×50. A sample was considered infested with *H. glycines* if one or more nematode eggs were observed.

If sufficient soil remained in a sample following extraction with the semiautomatic elutriator, a greenhouse bioassay test was performed as a second test for *H. glycines* infestation. Soil was placed in a 250-cm^3-capacity container, and three seeds of the susceptible soybean cv. Corsoy 79 were planted. Plants were thinned to one per container within 7 to 14 days after planting. After incubation at 26°C in a greenhouse for 28 to 35 days with a photoperiod of 16-h light and 8-h dark, soil was carefully removed from the roots of the plants and the roots were observed with the unaided eye for the presence of *H. glycines* females. If no females were detected, the roots were carefully soaked in water to remove the soil and were observed at ×12 with a dissecting microscope for the presence of *H. glycines* females. A sample was designated as infested with *H. glycines* if one or more females were observed on the roots of the soybean bioassay plants. If no eggs were detected in a soil

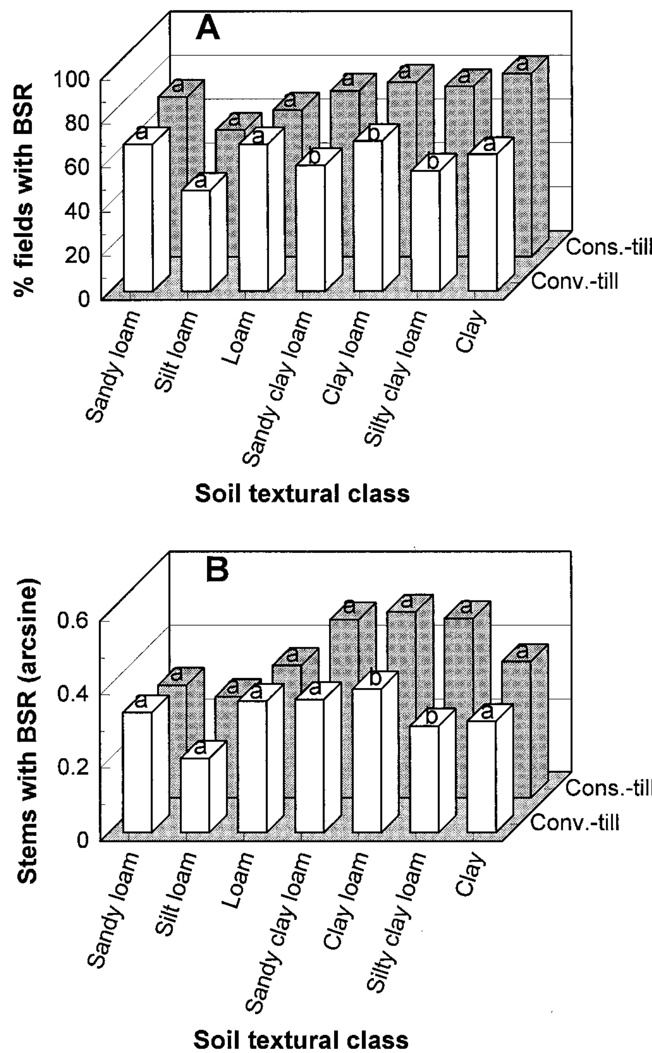

Fig. 1. Relationships **A,** between soil textural classes and the percentage of fields in which brown stem rot (BSR) was detected in conservation-till and conventional-till fields; and **B,** between the soil textural classes and the percentage of stems with brown stem rot (BSR, transformed to arcsine) in conservation-till and conventional-till fields. Bars with the same letter within a soil textural class are not significantly different according to **A,** chi-square tests ($P \leq 0.05$) and **B,** orthogonal contrasts ($P < 0.05$).

sample but the bioassay was positive, the sample was considered infested with *H. glycines*.

Data analyses. For brown stem rot and *P. sojae*, samples from no-till fields and minimum-till fields were classified in the category of 'conservation-till' for comparison with those from conventional-till fields, as described previously (36). For *H. glycines*, samples from conventional-till and minimum-till fields were classified as 'tilled' for comparison with no-till fields.

In this article, the term 'prevalence' is used to describe the percentage of fields in which the disease or the pathogen was detected, and the term 'incidence' is used to describe the percentage of samples from a field in which the disease or the pathogen was detected (40). Differences between tillage practices in the prevalence of brown stem rot, *P. sojae*, and *H. glycines* in different soil textures were determined with the chi-square test. The percentage of data from brown stem rot incidence and *P. sojae* isolation (percentage of leaf disks colonized) were transformed to arcsine, and population densities of *H. glycines* were transformed to logarithmic scale $\log_{10}(x + 1)$. Data from the 1995 and 1996 samples then were pooled and subjected to the analysis of variance (ANOVA) with all possible interactions using the general linear model (GLM) procedure in SAS (SAS Institute, Inc., Cary, NC). Linear orthogonal contrasts were used to compare tillage practices within each of the soil textural classes. To determine the effect of soil texture in each tillage system, the soil textural classes were ranked according to their percent clay and correlated with their rank in brown stem rot incidence, *P. sojae* isolation, or *H. glycines* population densities. The significance of the differences in ranks then were determined with Kendall's rank correlation coefficient.

RESULTS

According to the United States Department of Agriculture classification system, there are 12 soil textural classes with different combi-

TABLE 1. Summary of analysis of variance showing effects of tillage and soil texture on the incidence of brown stem rot (BSR), *Phytophthora sojae* recovery, and *Heterodera glycines* population densities showing mean squares (MS) and probability levels (*P*) in samples collected from five states of the north-central United States in the fall of 1995 and 1996

		BSR incidence[a]		*P. sojae* isolation		*H. glycines* density	
Source	df	MS	*P*	MS	*P*	MS	*P*
Tillage	1	1.1124	0.0006	0.0215	0.7018	18.3000	0.0030
Texture	6	0.7196	0.0001	2.7477	0.0001	8.8379	0.0003
Year	1	0.0923	0.3243	10.6628	0.0001	83.4953	0.0001
Tillage × texture	6	0.1451	0.1657	0.3969	0.0130	1.8427	0.5092
Tillage × year	1	0.0002	0.9624	0.6231	0.0396	3.4837	0.1953
Texture × year	6	0.2299	0.0250	0.1246	0.5327	4.6342	0.0377
Tillage × texture × year	6	0.0626	0.6819	0.1267	0.5222	0.9495	0.8599
Orthogonal contrasts[b]							
Tillage × sl	1	0.0095	0.7515	0.9809	0.0099	0.5612	0.6031
Tillage × sil	1	0.2979	0.0769	0.6519	0.0353	0.4571	0.6398
Tillage × l	1	0.0193	0.6518	0.9989	0.0092	6.2252	0.0835
Tillage × scl	1	0.3122	0.0701	0.0532	0.5471	3.9449	0.1682
Tillage × cl	1	1.0007	0.0012	0.0125	0.7705	5.3893	0.1073
Tillage × sicl	1	1.3581	0.0002	0.1523	0.3087	9.0918	0.0365
Tillage × c	1	0.0534	0.4532	0.0021	0.9048	9.7984	0.0299

[a] Incidence of BSR was not assessed in the 1995 samples from Missouri and in the 1995 and 1996 samples from Ohio.
[b] sl = Sandy loam, sil = silt loam, l = loam, scl = sandy clay loam, cl = clay loam, sicl = silty clay loam, and c =clay.

TABLE 2. Relationships between soil textural classes and incidence of brown stem rot (BSR) in samples from conservation-till and conventional-till fields

	Conservation-till			Conventional-till		
Soil textural class	No. of samples	% Clay[a]	Rank[b]	No. of samples	% Clay	Rank
Sandy loam	36	16.1	2	17	15.8	4
Silt loam	119	22.5	1	67	22.6	1
Loam	120	24.6	3	69	24.5	5
Sandy clay loam	57	24.7	5	43	25.0	6
Clay loam	188	32.4	7	142	32.8	7
Silty clay loam	97	33.5	6	45	33.3	2
Clay	24	45.5	4	34	43.7	3

[a] Mean percentage of clay in the soil textural class for the corresponding samples.
[b] Ranks for the soil textural classes were generated based on the incidence of BSR. Soil textural class with rank 1 had the lowest incidence of brown stem rot. Kendall's rank correlation for conservation-till is $r = 0.52$, $P = 0.10$; and for conventional-till is $r = 0.14$, $P = 0.66$.

TABLE 3. Relationships between soil textural classes and isolation frequency of *Phytophthora sojae* in samples from conservation-till and conventional-till fields

	Conservation-till			Conventional-till		
Soil textural class	No. of samples	% Clay[a]	Rank[b]	No. of samples	% Clay	Rank
Sandy loam	43	15.5	1	23	13.9	5
Silt loam	151	22.5	2	79	22.5	1
Loam	188	24.0	3	105	24.3	2
Sandy clay loam	62	24.8	5	48	25.0	4
Clay loam	228	32.4	6	180	33.1	6
Silty clay loam	110	33.6	4	51	33.6	3
Clay	67	46.4	7	55	45.2	7

[a] Mean percentage of clay in the soil textural class for the corresponding samples.
[b] Ranks for the soil textural classes were generated based on the detection frequency of *P. sojae*. Soil textural class with rank 1 was the least in the detection frequency of *P. sojae*. Kendall's rank correlation for conservation-till is $r = 0.81$, $P = 0.01$; and for conventional-till is $r = 0.43$, $P = 0.18$.

nations of sand, silt, and clay particles (12). There were not enough samples from five of the soil textural classes (sand, loamy sand, silt, sandy clay, and silty clay) to include in the analysis; therefore, their influence on the effects of tillage practices was not determined.

The prevalence of brown stem rot was affected by different combinations of soil texture and tillage. In sandy clay loam, clay loam, and silty clay loam soils, the prevalence of brown stem rot was greater ($P \leq 0.05$) in conservation-till fields than in conventional-till fields (Fig. 1A). However, in sandy loam, silt loam, loam, and clay soils, the difference in prevalence of the disease between the two tillage categories was not as apparent.

The incidence of brown stem rot in each field was significantly affected by both tillage and texture (Table 1). However, the interaction between tillage and texture was not significant, indicating that the effect of tillage on the incidence of brown stem rot was similar in all soil textural classes. There was no significant difference in the incidence of brown stem rot between the 2 years. The interaction between tillage and year also was not significant, which suggested that the effects of tillage did not vary from year to year. In contrast, the year × texture interaction was significant, suggesting that the effect of soil texture on the incidence of brown stem rot was not consistent from year to year. The tillage × texture × year interaction was not significant; the effect of tillage was consistent from year to year in all soil textural classes.

Orthogonal contrasts of the effect of individual soil textural classes on the incidence of brown stem rot showed that tillage had a significant effect on the incidence of brown stem rot in clay loam and silty clay loam soils ($P = 0.0012$ and $P = 0.0002$, respectively) (Table 1). In these two soil textural classes, conservation tillage had a greater incidence of brown stem rot than did conventional tillage (Fig. 1B). No significant differences in the incidence of brown stem rot were detected among the rest of the soil textural classes and tillage.

Within tillage categories, the incidence of brown stem rot varied slightly with clay content. In conservation-till fields, there was a weak, positive correlation between clay content and the ranks of the soil textural classes based on the incidence of brown stem rot ($r = 0.52$, $P = 0.10$) (Table 2). In contrast, there was little or no association between the brown stem rot ranks and clay content in conventional-till fields ($r = 0.14$, $P = 0.66$).

The effect of tillage practices on the prevalence of *P. sojae* depended on the soil texture. In loam soils, *P. sojae* was detected in more conservation-till fields than in conventional-till fields ($P = 0.013$) (Fig. 2A). However, in sandy loam soils, *P. sojae* was detected in more conventional-till fields than in conservation-till fields ($P = 0.018$). There was no significant difference in the prevalence

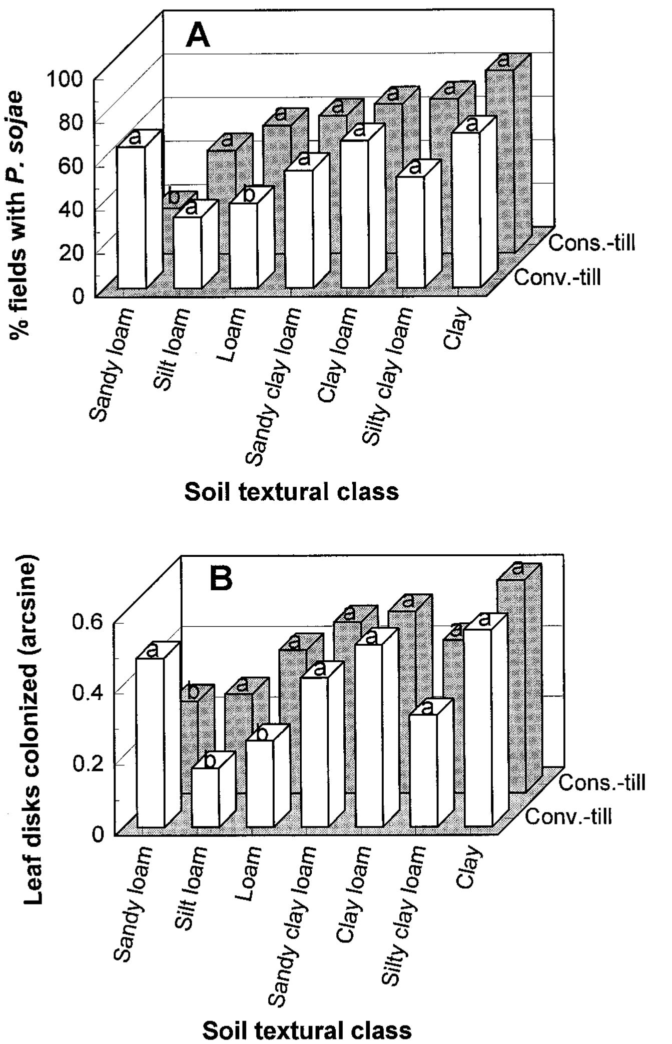

Fig. 2. Relationships **A,** between soil textural classes and the percentage of fields in which *Phytophthora sojae* was detected in conservation-till and conventional-till fields; and **B,** between the soil textural classes and the isolation of *P. sojae* (transformed to arcsine) in conservation-till and conventional-till fields. Bars with the same letter within a soil textural class are not significantly different according to **A,** chi-square tests ($P < 0.05$) and **B,** orthogonal contrasts ($P < 0.05$).

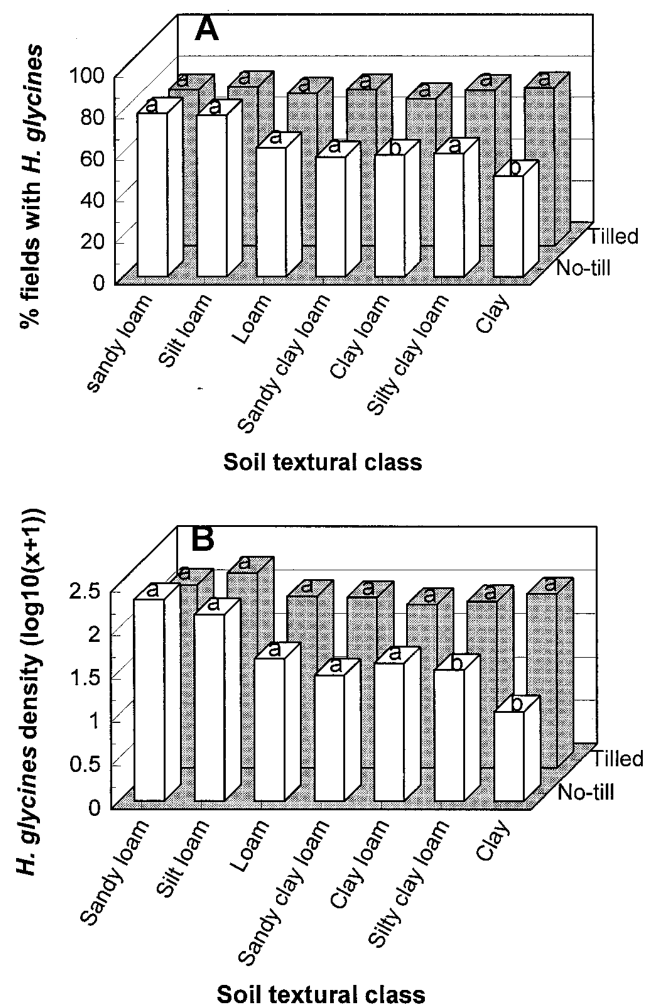

Fig. 3. Relationships **A,** between soil textural classes and the percentage of fields in which *Heterodera glycines* was detected in conservation-till and conventional-till fields; and **B,** between the soil textural classes and egg densities of *H. glycines* (transformed to $\log_{10}[x + 1]$) per 100 cm^3 of soil in conservation-till and conventional-till fields. Bars with the same letter within a soil textural class are not significantly different according to **A,** chi-square tests ($P < 0.05$) and **B,** orthogonal contrasts ($P < 0.05$).

of *P. sojae* between the tillage categories and each of the remaining soil textural classes.

The ANOVA showed that there was no difference between the tillage categories in detection of *P. sojae* (Table 1); however, tillage significantly interacted (P = 0.013) with texture, indicating that the effect of tillage practices on the detection frequency of *P. sojae* was influenced by soil texture. Highly significant differences in the detection of *P. sojae* were observed among the soil textural classes and between the 2 years. Also, there was a significant interaction between tillage and year, but interaction between texture and year was not significant. The effect of soil texture was consistent from year to year. Tillage × texture × year interaction also was not significant, which suggested that the relationship between tillage and texture in the detection of *P. sojae* was similar in both years.

The orthogonal contrasts between tillage and the soil textural classes showed that tillage had significant effects on the detection of *P. sojae* in sandy loam, silt loam, and loam soils (Table 1). In sandy loam soils, there was a greater detection frequency of *P. sojae* in conventional tillage than in conservation tillage. However, in silt loam and loam soils, a greater detection frequency of *P. sojae* occurred in conservation tillage than in conventional tillage (Fig. 2B). There were no significant effects of tillage in sandy clay loam, clay loam, silty clay loam, and clay soils.

Within each tillage category, the detection frequency of *P. sojae* was positively associated with clay content. In conservation-till fields, the ranks of the soil textural classes based on the detection of *P. sojae* strongly correlated with percent clay (r = 0.81, P = 0.01) (Table 3), whereas in the conventional-till fields, the relationship was not as strong (r = 0.43, P = 0.18).

H. glycines was detected in more tilled fields than in no-till fields in clay loam, silty clay loam, and clay soils (P = 0.038, 0.056, and 0.002, respectively) (Fig. 3A). There was no difference in the prevalence of *H. glycines* between the two tillage categories in sandy loam, silt loam, loam, and sandy clay loam soils.

In the ANOVA, all three of the main effects (tillage, texture, and year) significantly affected the population densities of *H. glycines* (Table 1). Unlike the recovery of *P. sojae*, there was no interaction between tillage and texture in *H. glycines* population densities. Also, the interaction between tillage and year was not significant; the effect of tillage on the population densities of *H. glycines* was similar in both years. There was a significant texture × year interaction, suggesting that the effect of soil texture on the population densities of *H. glycines* varied between the 2 years. However, the interaction between the three main effects, tillage × texture × year, was not significant. The tillage × texture interaction was similar in both years.

The orthogonal contrasts between tillage categories and each of the soil textural classes showed that tillage had a significant effect on *H. glycines* population densities in clay and silty clay loam soils (Table 1). In these soils, no-till fields had significantly lower population densities of *H. glycines* than did tilled fields (Fig. 3B). Population densities of *H. glycines* were not significantly affected (P > 0.05) by tillage in any of the other soil textural classes.

There was a strong negative correlation (r = –0.81, P = 0.01) between percent clay and population densities of *H. glycines* in no-till fields (Table 4). However, in tilled fields, the relationship between the population densities of *H. glycines* and percent clay was less strong (r = –0.43, P = 0.18).

DISCUSSION

Numerous studies have demonstrated the effects of tillage practices on various plant diseases or pathogens (2,20,26,27); however, none explored the possible confounding effects of soil texture. The current study is the first report describing the relationships among soil texture, tillage, and diseases or pathogens. In the analysis, blocking the effects of tillage practices by soil textural class was instrumental in separating the effects of tillage from those of soil texture. In addition, partitioning of the treatment sums of squares with single-degree of freedom contrasts was helpful in comparing the effects of tillage practices within each of the soil textural classes.

Previous studies have shown that the incidence and severity of soybean brown stem rot was greater in conservation tillage practices than in conventional tillage practices (2,36). The current study demonstrated that both soil texture and tillage have a significant effect on the incidence of brown stem rot. Although the overall tillage × texture interaction was not significant, conservation-till fields had a significantly greater incidence of brown stem rot than did conventional-till fields in clay loam and silty clay loam soils. The difference in incidence of brown stem rot between the tillage systems appears to be more pronounced in fine-textured than in coarse-textured soils. *Phialophora gregata* multiplies profusely on infested surface residue (1). Fine-textured soils, coupled with abundant surface residue in conservation tillage, may have retained greater moisture than did coarse-textured soils, creating a favorable environment for an increase in the population density of the pathogen. The increase in population density may have led to a greater chance of infection in conservation-till than in conventional-till fields in the fine-textured soils. It is interesting that, in both tillage systems, there was a similar trend in the incidence of brown stem rot in relation to soil texture. The brown stem rot incidence generally increased with increasing clay content and was maximum in sandy clay loam and clay loam soils, after which it declined as the clay content increased. It is not clear why the brown stem rot incidence showed such a pattern of distribution in relation to soil texture. The relationship between soil texture and brown stem rot prevalence and incidence requires further investigation.

Soil texture significantly interacted with tillage in the detection of *P. sojae*. In silt loam and loam soils, the recovery of *P. sojae* was greater in conservation-till fields than in conventional-till fields. However, in soils with clay content greater than that of silt loam and loam, there was no significant difference in the detection frequency of *P. sojae* between the tillage categories. Fine-textured soils have a greater water-holding capacity than do coarse-textured soils and, hence, often are associated with diseases caused by *Phytophthora* spp., which are favored by such conditions (11). In fine-textured soils, the effect of clay may have a greater impact on the abun-

TABLE 4. Relationships between soil textural classes and population densities of *Heterodera glycines* in samples from tilled and no-till fields

Soil textural class	No-till			Tilled		
	No. of samples	% Clay[a]	Rank[b]	No. of samples	% Clay	Rank
Sandy loam	19	14.5	7	48	15.2	6
Silt loam	78	22.3	6	152	22.5	7
Loam	85	23.2	5	208	24.5	4
Sandy clay loam	19	24.3	2	91	24.9	3
Clay loam	86	33.1	4	322	32.6	1
Silty clay loam	48	33.9	3	113	33.5	2
Clay	43	46.7	1	79	45.2	5

[a] Mean percentage of clay in the soil textural class for the corresponding samples.

[b] Ranks for the soil textural classes were generated based on the population densities of *H. glycines*. Soil textural class with rank 1 had the lowest population densities of *H. glycines*. Kendall's rank correlation for no-till is r = –0.81, P = 0.01; and for tilled is r = –0.43, P = 0.18.

dance of *P. sojae* than does tillage. The detection frequency of *P. sojae* was positively associated with percent clay regardless of the tillage system, with the exception of sandy loam. In soils with high clay content, the effect of tillage may have been masked by that of clay. In silt loam and loam soils, the confounding effect of clay is minimal, and the significant differences observed may be solely attributed to differences in tillage practices.

In sandy loam soil, the isolation frequency of *P. sojae* was greater in conventional-till fields than in conservation-till fields. Soils with high sand content, in addition to low clay content, are low in organic matter content. Therefore, such soils are structurally unstable and, consequently, are susceptible to compaction by agricultural equipment (28). Generally, there are more field operations in a season in conventional-till than in conservation-till fields, which means more equipment traffic and more compaction in conventional-till than in conservation-till fields. In this study, the fact that there was a greater detection frequency of *P. sojae* in conventional-till than in conservation-till fields in sandy loam soil may be attributed, at least in part, to the compaction caused by agricultural equipment.

The effects of tillage and soil texture on population densities of *H. glycines* have been described by various investigators. It is well documented that reproduction of nematodes, including *H. glycines*, is greater in coarse-textured than in fine-textured soils (24,33,39). However, reports on the effect of tillage practices on the population densities of *H. glycines* are conflicting. Tyler et al. (34) and Koenning et al. (16) reported lower population densities of *H. glycines* in no-till than in conventional tillage. However, Hershman and Bachi (13) and Stienstra et al. (32) did not detect tillage effects, while Niblack et al. (23) reported the effects of tillage to be inconsistent. In our study, both the prevalence and population densities of *H. glycines* decreased with increasing clay content in samples from no-till fields. However, there was only a slight variation in the population densities of *H. glycines* due to changes in soil texture in samples from tilled fields. The difference between the tillage categories was significant only in samples with high clay content (silty clay loam and clay). The conflicting reports on the effect of tillage practices, therefore, may be attributed to variations in soil texture.

It is not clear why no-till fields had lower population densities of *H. glycines* than did tilled fields in clay soils. Based on greenhouse studies, Young and Heatherly (39) concluded that the differences between loam and clay soils in the population densities of *H. glycines* was not due to differences in penetration of roots by juveniles, but due to the rate of nematode reproduction. However, Johnson et al. (14) reported that root penetration by *H. glycines* juveniles was positively correlated with soil oxygen diffusion rates and negatively correlated with soil water potential. Soils with high clay content are characterized by prolonged saturation after rain events and, thus, have lower oxygen diffusion rates than do soils with low clay content. Similarly, no-till fields generally contain more moisture than do tilled fields, mainly because of the associated surface residue (17). It is not surprising, therefore, that no-till fields with high clay content had significantly lower population densities of *H. glycines* than did tilled fields. In tilled fields, repeated soil disruption during land preparation and cultivation may have alleviated oxygen deficiencies arising from saturation due to high clay content.

Another possible explanation for the inverse relationships between *H. glycines* population densities and soil clay content is the differential efficiency of extraction of the nematode. In order for *H. glycines* eggs to be extracted and counted, soil particles must disperse in the elutriator to release the egg-filled cysts. Differences would be likely in magnitude of soil dispersion among soil textural classes or between samples from no-till and tilled fields within a soil textural class. Although dishwashing detergent was used as a dispersing agent during extraction of the nematode cysts, parity in the extraction efficiency among the soil textural classes or between the tillage categories of similar soil texture may not have been achieved. However, the differences in the egg population densities between sandy soil and clay soil in samples from no-till fields and between no-till and tilled clay soils are greater than 10-fold. Therefore, the observed differences probably cannot be solely attributed to the lack of parity in nematode extraction efficiency.

Overall, this regional investigation provided interesting information on the effect of tillage practices on the activities of the three pathogens in soils with various soil texture. For the incidence of brown stem rot, differences between conservation tillage and conventional tillage widened with increasing clay content. However, the trend in the incidence of brown stem rot in relation to soil texture was similar in both tillage categories. Conversely, the difference in the detection of *P. sojae* between the tillage categories diminished as clay content increased, probably due to the confounding effects of clay. The frequency of fields in which *P. sojae* was detected increased with increasing clay content, and the relationship was stronger in conservation tillage than in conventional tillage. In sandy soils, the population densities of *H. glycines* were similar in both tillage categories. However, in soils with greater clay content, tilled fields had greater densities of *H. glycines* than did no-till fields. In no-till fields, population densities of *H. glycines* were inversely correlated with clay content, whereas in tilled fields, there was little or no effect of clay content on nematode densities.

The study demonstrated that soil texture influences the relationships between tillage and the incidence of brown stem rot, isolation of *P. sojae,* and population densities of *H. glycines*. These findings emphasize the need for cautious interpretation of the effects of tillage practices on diseases and pathogens in the absence of information on soil texture.

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